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Enhancement of the Core Safety of a Conceptual SCWR Core

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1. Introduction

A preliminary conceptual SCWR core design with a cruciform-type ZrH_2 solid moderator has been presented at the ICAPP06.[1] In the meantime, efforts have been made to improve the design to meet the Gen-IV requirements[2]. In this paper, the results of the modifications of the previous design are presented, where an enhancement of the core safety has been made in terms of the power peaking factor and maximum coolant temperature.

2. Methods and Results

2.1 Modification of Fuel and Burnable Poison Design

This study focuses on the design modifications of the fuel geometries and the arrangement of the burnable poison and control rod. The neutron moderation capability was improved by replacing 16 fuel pins with 16 solid moderator pins. The improved fuel assembly is composed of 300 fuel rods, 25 cruciform-type solid moderators and 16 single pin solid moderators.

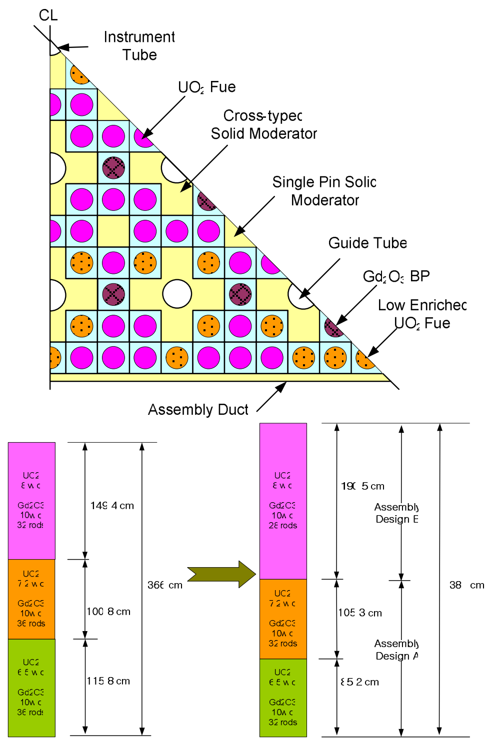

Fig. 1. Cross-sectional view of assembly model and axial zoning of fuel and burnable poison rod.

The fuel enrichment remains the same, but the axial length of each region is changed as shown in Fig. 1. To meet the design goal of the fuel cycle burnup proposed in the Gen-IV roadmap, the core height was increased from 366cm to 381cm. Compared with the previous design the length of the top region was increased by 41.1cm and the bottom region was decreased by 30.6 cm. The number of gadolinia rods was decreased from 36 to 32 for the bottom and the middle regions of the core, and from 32 to 28 for the top region of the core. The content of Gd_2O_3 in a gadolinia rod was set as 10 w/o.

2.2 Control of Excess Reactivity and Coolant Flow

Although the fuel loading pattern has not been changed, the coolant flow rate of each orifice was adjusted to reduce the maximum coolant temperature at the core outlet. The excess reactivity of the modified conceptual SCWR core was increased due to the fact that the number of the burnable poison rods was decreased, and the height of the core and the volume of the high enriched fuel region were increased. The distribution of the flow rates to minimize the maximum coolant temperature of the modified conceptual SCWR core is presented in Fig. 2. The flow rate of each orifice was determined so that the coolant temperature was minimized during a burnup period.

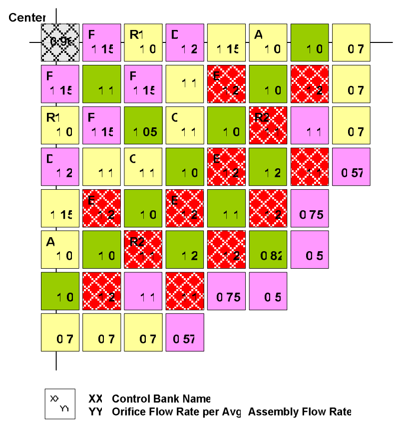

Fig. 2. Loading pattern of a Equilibrium Core with Control Banks and Orifice Flow Rates

Six types of control banks to control the excessive reactivity and the power distribution were introduced in the previous study. In this study, an additional length (containing 100cm of neutron absorber material) of the control bank was introduced for the axial power shape control only. The length of the absorber in the control banks is the same as that of the fuel.

Table 1. Summaries of Reactivity Requirements and Shutdown Margins

Description	BOC	MOC	EOC
A. Control Rod Requirements at CZP (%Δ ρ)			
HFP Excess Reactivity	3.87	2.57	1.03
Xenon Reactivity	2.47	2.53	2.63
FHP to HZP, Power Defect	5.77	6.17	6.75
HZP to CZP, Temperature Defect	1.43	1.40	1.45
Total Requirements	13.53	12.67	11.85
B. Control Rod Scram Worth (N-1) at CZP (%Δ ρ)			
Total Rod Worth	22.21	22.29	22.60
Most Reactive Stuck Rod Worth	5.88	5.55	5.50
Net Rod Worth	16.33	16.74	17.10
10% Uncertainty	1.63	1.67	1.71
Remaining Scram Worth	14.69	15.06	15.39
C. Control Rod Scram Worth (N-1) at CZP (%Δ ρ)			
Calculated Shutdown Margin(B-A)	1.16	2.39	3.54

In order to control the excess reactivity, eight A-type CR banks were replaced by a R2 bank and 4 R1 banks were added as shown in Fig. 2. All the control banks are assumed to move individually without any systematic overlap mechanism. Partially loaded CR banks, R1 and R2 are placed at the positions where the peak power occurs.

2.3 Results of Analysis

The equilibrium core state was obtained after many transition cycles. Since the maximum coolant temperature primarily depends on the coolant flow rate, the coolant flow rate distribution was adjusted for each cycle. The critical state of the core was maintained by adjusting the insertion rate of the control rod banks. Therefore, after adjusting the core flow distribution to meet the maximum coolant temperature limit, the critical positions of the control rod banks were searched for each cycle. Both the calculations for the adjustment of the flow distribution and the critical position of the control rod banks were repeated until a steady state was reached between the coolant temperature and the core critical state. It was assumed that the k_{eff} within the range of 5 pcm around 1.0 is critical during a burnup calculation. The fuel cycle length with the design modification was calculated and found to be 42GWd/tHM. The maximum relative axial power was 1.45 at EOC, which is almost the same as that of a conventional PWR. The maximum power peaking factor was 2.45 at BOC which is much lower than the design limit of 2.7. The power peaking factor decreases with the burnup increase until MOC since the axial power shape becomes stabilized according to the withdrawal of the control banks. After adjusting the flow rate for each fuel assembly channel, the maximum coolant temperature was reduced from 730°C to 577°C at BOC. The maximum coolant temperature occurred at the core peripheral during a burnup because of the small coolant flow rates in the outermost fuel assembly channel. The coolant temperature coefficient including the effect of the coolant density change varied from -22 pcm/°C at BOC to -23 pcm/°C at EOC. The fuel temperature coefficient decreases slightly from -2.0 pcm/°C at BOC to -2.1 pcm/°C at EOC with an increase of the fuel burnup rate. The shutdown margin has been evaluated and the result is shown in Table 1. The total control rod worth requirements from HFP to CZP includes the power defect from HFP to HZP, the xenon reactivity, and the excessive reactivity at HFP. The control rod worth requirement decreases with the burnup increase due to the reduced excess reactivity. As shown in Table 1, the calculated shutdown margin exceeds the shutdown margin requirement by 1% $\Delta\rho$ with a 10% uncertainty for the whole burnup period.

3. Conclusion

An improvement of a conceptual core design with a 1400MWe SCWR power generation has been made as a continuation of a previous design by focusing on an enhancement of the core safety. The power peaking factor decreased from 2.69 to 2.48 and the maximum coolant temperature also decreased from 586°C to 577°C as the result of an axial zoning modification of the fuel and BP and a precise adjustment of the partial control rod and orifice flow rate. The improved core design provides an enough shutdown-margin during the investigated burnup period.

REFERENCES

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